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EXPERIMENTAL EVALUATION OF SMALL-SCALE ERECTABLE TRUSS HARDWARE

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INTRODUCTION

To aid in the development of test and suspension techniques for ground testing of large space structures, a one-tenth scale dynamic test model of a Space Station-size structure is to be constructed of commercially-available, small-scale truss hardware[1]. A finite element model of the test article is also being developed to allow for comparison between predicted and measured dynamic behavior. This paper summarizes the results of tests that have been performed to determine the axial stiffness characteristics and failure loads of the small-scale truss joints. An effective stiffness of a strut-joint combination has also been determined to allow it to be properly represented in the finite element model.

Identification of commercial products in this report is used to describe adequately the test hardware. The identification of these commercial products does not constitute official endorsement, expressed or implied, of such products by the National Aeronautics and Space Administration.

TEST DESCRIPTION

Test Hardware

The truss to be constructed for the Space Station dynamic test model will be one-tenth scale only in bay size. The hardware does not represent scaled Space Station hardware; however, it is functionally similar to structural concepts proposed for Space Station. The truss hardware consists of aluminum struts interconnected at spherical nodes (see figure 1). The nodes are hollow aluminum spheres with eighteen threaded holes for strut attachment. They have a steel bolt attached to each end by means of a bonded, interference fit aluminum plug. For the purpose of subsequent analysis, the inside end of this plug is considered to be the outer boundary of the joint. Therefore, the joint includes the plug, bolt and spherical node. In this study, two different types of specimens were tested: a joint subassembly consisting of a node with a strut half mounted on either side, and a segment of a strut having the same length as the joint subassembly.

Test Set Up

The Material Testing System (MTS) material testing machine was used to provide tensile/compressive load cycling in all of the tests (see figure 2). The MTS

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1. Meroform M 12: Trade name of MERO-Raumstruktur GmbH & Co., Wurzburg, West Germany.

machine employs a hydraulic gripping system to hold the test specimen. Toaccommodate this system, the end of each strut to be placed in the machine was fitted with a solid aluminum plug, (see figure 3). This was done to prevent the strut from being crushed. Three differential current displacement transducers (DCDT's) were mounted around the test specimens and their deflections averaged to compensate for any bending that occurred in the specimens (see figure 4). Mounting plates were placed two inches inside of the strut-end plugs to measure total displacement of the joint and strut ends.

Test Matrix

Table 1 outlines the specimen designations and tests performed. The strut segment (specimen #1) was tested first to determine its stiffness and to calibrate the system to ensure the test set-up was operating properly. The strut was cycled, quasi-statically, through tensile and compressive loads of approximately 200 lb. for five cycles.

After verifying the test procedure, a joint subassembly (specimen #2) was loaded in tension to determine its failure load and thus determine a desirable upper load limit for testing the remaining joints (1000 lb. was chosen).

A parametric study was conducted on the next joint subassembly (specimen #3) to determine the effect of the attachment bolt torque value on joint stiffness. To accomplish this, tests using four torque values (50 in.-lb., 150 in.-lb., 250 in.-lb. and 300 in.-lb.) were conducted. For each torque value, the specimen was cycled through +/- 200 lb. for five cycles. Similarly, it was cycled through +/- 1000 lb. for five cycles to determine if the torque value effects would change at higher loads.

The remaining two specimens (#4 and #5) were tested through the same load cycles as specimen #3, each at the torque value of 250 in.-lb. This was done to determine the stiffness variation between joints. Furthermore, each specimen was failed to obtain data on the failure loads and corresponding failure modes of the joint.

RESULTS

Strut Stiffness

The load-deflection curve for the strut (specimen #1) is shown in figure 5. Because the strut segment should behave linearly, the anomaly present at the origin (change in slope) is believed to be due to a problem in the test machine that has not yet been determined. As expected, the slope of the tensile and compressive portions of the curve are very nearly equal, differing only by 0.86 percent.

From this curve, the experimentally determined stiffness is 9.37×10^5 lb. This is computed by multiplying the slope of the load-deflection curve by the test article length (16.0 in.) which yields the stiffness, EA. Assuming a material Young's modulus of 10×10^6 psi. and a cross sectional area of .0976 $in.^2$ (.868 in. outer diameter, .0374 in. wall thickness), the predicted stiffness is 9.76×10^5 lb. This represents a difference of only 4.16 percent

from the experimentally determined value, and, thus, verifies the test proceedure.

Joint Stiffness

The parametric study performed on specimen #3 shows that the structural performance of the joint does improve as the attachment bolt torque value is increased. As shown in the load-deflection plots in figures 6a and 6b, the hysteresis that is present in the test conducted with 50 in.-lb. of torque is nearly nonexistent in the test conducted with 250 in.-lb. of torque. This reduction is a result of the increased pre-load in the threaded connections between the node and strut at the higher torque values. The anomaly present at the origin in these curves is similar to that shown for specimen #1 (figure 5) and may be due to thread play as well as the aforementioned load machine problem.

Furthermore, as shown in table 2, the stiffness of the joint increases from 1.385×10^6 lb. to 1.846×10^6 lb. (33.3 percent increase) when the torque value was raised from 50 in.-lb. to 300 in.-lb. However, in the tests run with the higher load limits of +/- 1000 lb. (see figure 7), there was a slight shift in the zero-load deflection on each subsequent load cycle. As seen in table 2, this shift was between 1.18×10^{-4} in. and 2.12×10^{-4} in. for the various attachment bolt torque values. This shift may be a result of plasticity in the threads on the node, or it may be due to slippage in the bonded plug.

The joint stiffness remained relatively constant between specimens #3, #4 and #5 as shown in table 3. The data shown is for the +/- 200 lb. loadings with a torque value of 250 in.-lb. The maximum difference between any two values is 10.93 percent. The average joint stiffness as a percentage of strut stiffness is 183 percent.

It is of interest to determine the change in stiffness of the strut-joint combination due to the presence of the joint. From table 3, the stiffness of the strut (EA_s) is 0.937×10^6 lb., and the average stiffness of the joint (EA_j) is 1.711×10^6 lb. For the joint subassembly tested L_s = 8.0 in. and L_j = 6.0 in. (see figure 8), using the following expression (ref. 1) for the effective stiffness (EA_e) results in a value of 1.162×10^6 lb. This represents a 24 percent increase in stiffness over that of the strut.

$$EA_e = \frac{L(EA_s)(EA_j)}{(L_s(EA_j)+L_J(EA_s))}$$

Joint Failures

The joint subassemblies failed in the area of the bonded plug in both tension and compression. The plug was pulled out of the tube when loaded in tension, while it was forced into the tube when loaded in compression. Two specimens were failed in tension, and two in compression. Tensile failures occurred at 3123.75 lb. and 2806.25 lb., and the compressive failures occurred at 2596.25 lb. and 2221.25 lb. The lower failure load in compression is due to the Poisson Ratio effect. As the specimen is loaded in tension, the tube constricts slightly. This increases the normal force acting on the bonded

plug, and increases the failure load. The opposite is true for the compressive cases.

CONCLUSIONS

Tests have been performed to determine the axial stiffness characteristics and failure loads of a small scale truss hardware joint. A parametric study has shown that the stiffness of the joint increases as the attachment bolt torque value is increased. Furthermore, at torque values equal to or higher than 250 in.-lb., hysteresis in the load deflection curve is essentially eliminated. Also, the joint stiffness remained relatively constant between specimens. The effective cross sectional stiffness (EA_e) of the strut-joint subassembly tested is 124 percent that of the strut. Tensile and compressive failure occurred in the region of the bonded plug, with lower failure loads corresponding to compressive loadings.

REFERENCE

1. Timoshenko, S. P.; Young, D. H.: Theory of Structures. McGraw-Hill, Inc., 1965.

TABLE 1.- SUMMARY OF TESTS PERFORMED

TEST MATRIX

	LOAD CASES		
SPECIMEN	+/- 200 LBS	+/- 1000 LBS	FAILURE
# 1 STRUT	5 CYCLES	-	-
# 2 JOINT SUBASSEMBLY	-	-	TENSION
# 3 JOINT SUBASSEMBLY	4 TORQUES 5 CYCLES	4 TORQUES 5 CYCLES	COMPRESSION
# 4 JOINT SUBASSEMBLY	250 IN-LBS 5 CYCLES	250 IN-LBS 5 CYCLES	TENSION
# 5 JOINT SUBASSEMBLY	250 IN-LBS 5 CYCLES	250 IN-LBS 5 CYCLES	COMPRESSION

TABLE 2. - DEPENDENCE OF JOINT STIFFNESS ON ATTACHMENT BOLT TORQUE VALUE

Specimen #3

	+/- 200 lb.		+/- 1000 lb.	
TORQUE VALUE (in-lbs)	STIFFNESS ($lbs \times 10^{6}$)	HYSTERESIS WIDTH ($in \times 10^{-5}$)	STIFFNESS ($lbs \times 10^{6}$)	SHIFT WIDTH ($in \times 10^{-4}$)
50	1.385	8.82	1.162	1.88
150	1.698	7.06	1.609	1.41
250	1.698	-	1.733	1.18
300	1.846	-	1.745	2.12

TABLE 3.- STIFFNESS VARIATION BETWEEN JOINT SPECIMENS

	STIFFNESS* ($lbs \times 10^{6}$)	% DIFFERENCE WITH SPECIMEN:			% of STRUT STIFFNESS
STRUT	0.937	3	4	5	-
SPECIMEN 3	1.698	-	6.42	4.24	181
SPECIMEN 4	1.807	6.42	-	10.93	193
SPECIMEN 5	1.629	4.24	10.93	-	174

* Stiffness numbers given for specimens 3,4 and 5 are the stiffnesses of the joint sections only of those specimens.

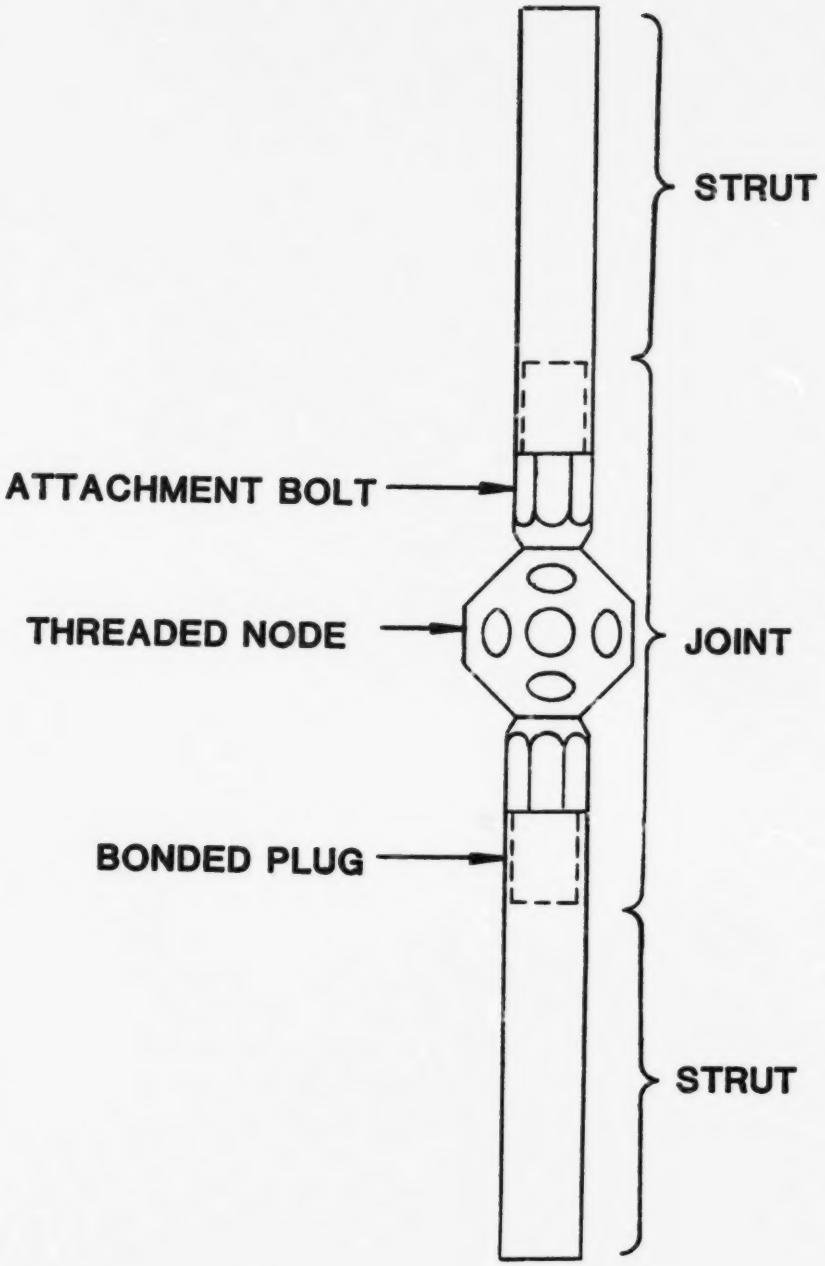

Figure 1.– Joint Subassembly

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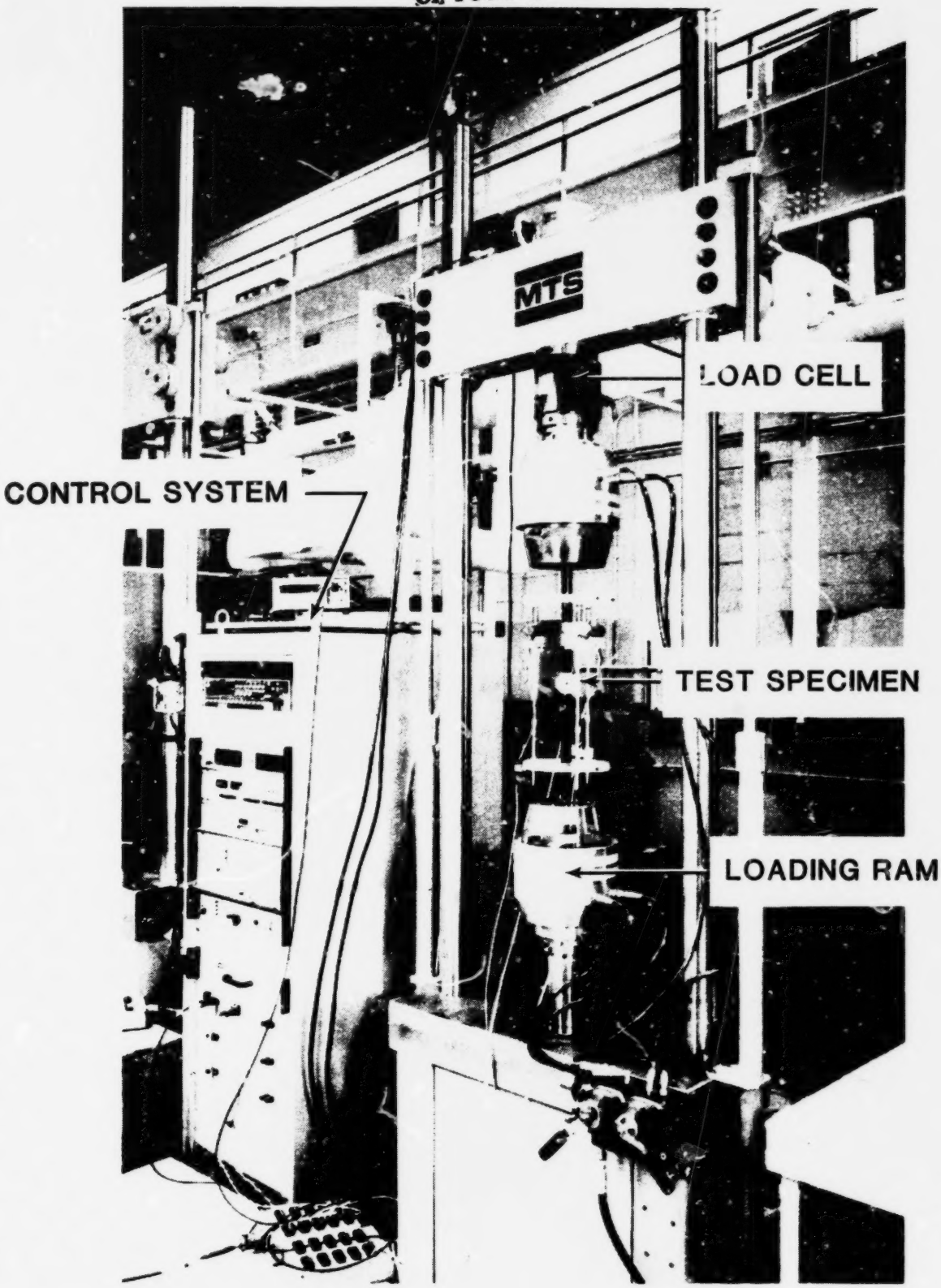

Figure 2. – MTS Test Machine

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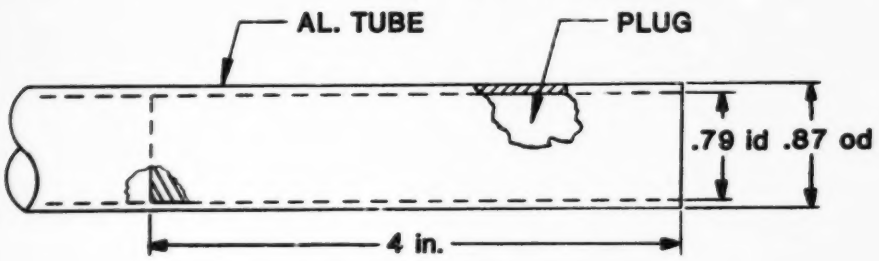

Figure 3. – Plugged Strut End

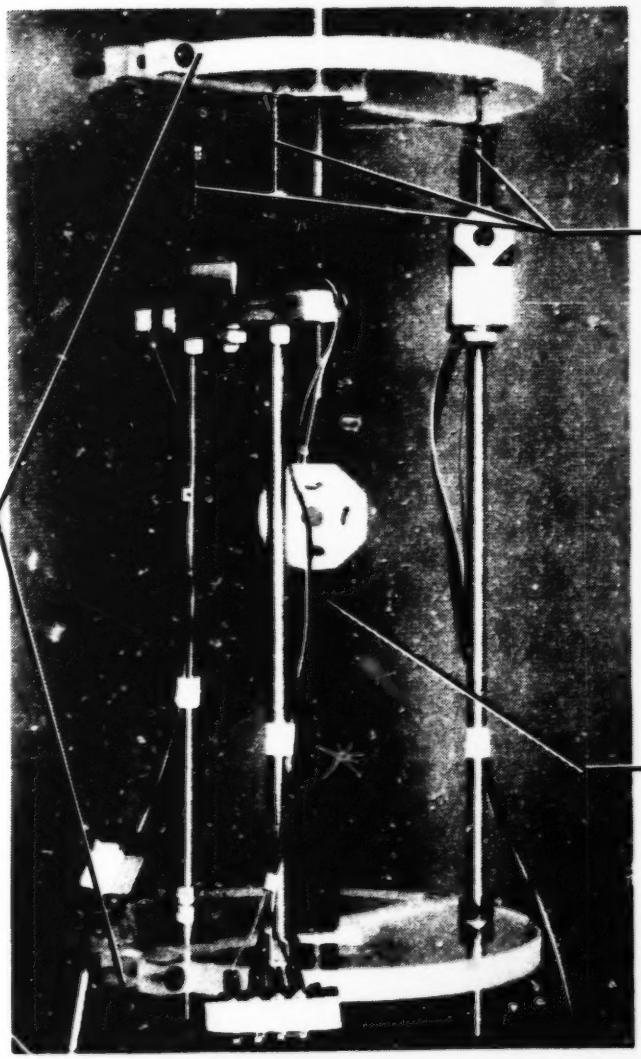

Figure 4. – Test Set–Up

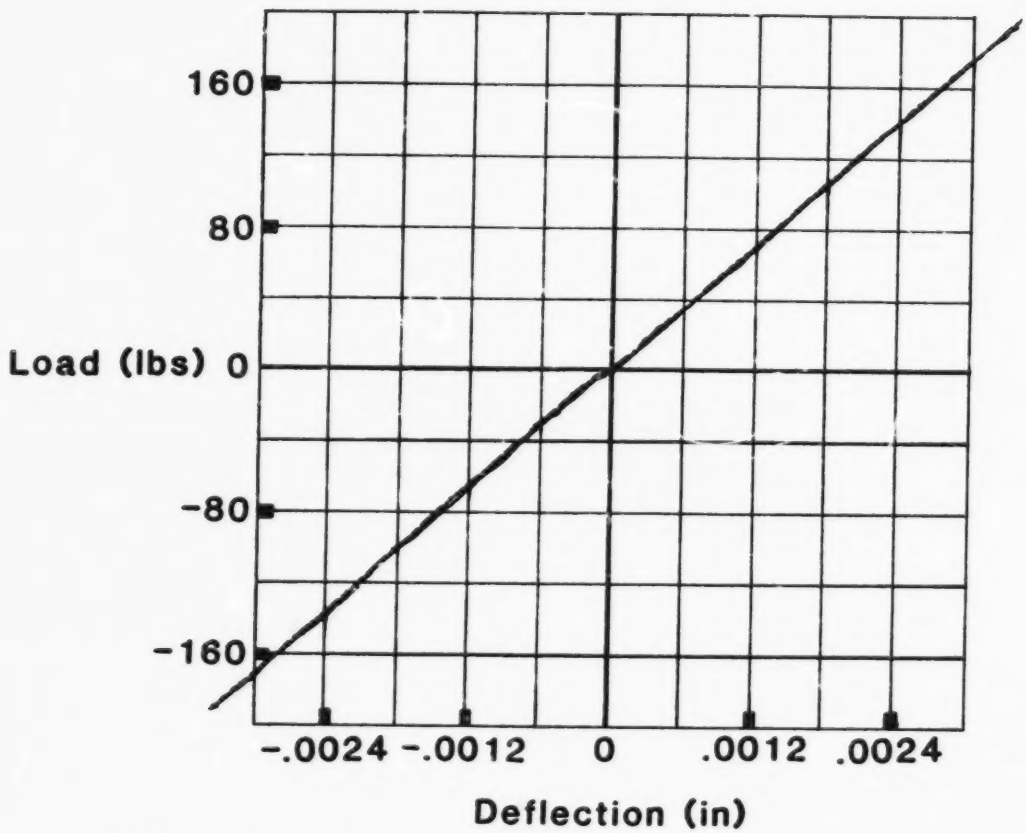

Figure 5. - Load-Deflection Curve for Specimen # 1 (Strut)

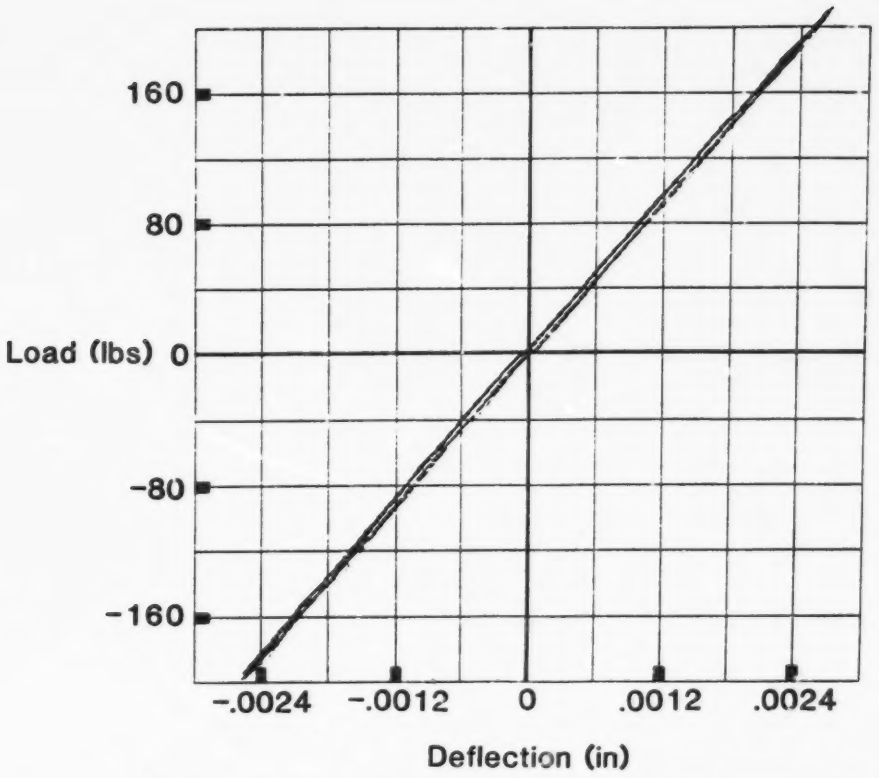

Figure 6a. – Load–Deflection Curve for Specimen # 3 with 50 in–lbs Torque

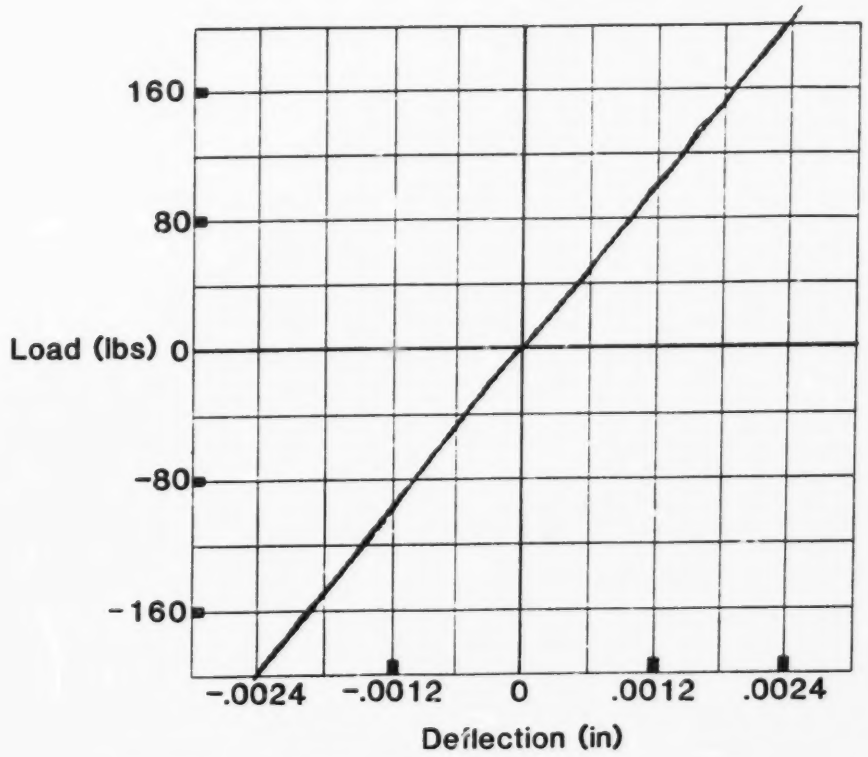

Figure 6b. – Load–Deflection Curve for Specimen # 3 with 250 in–lbs Torque

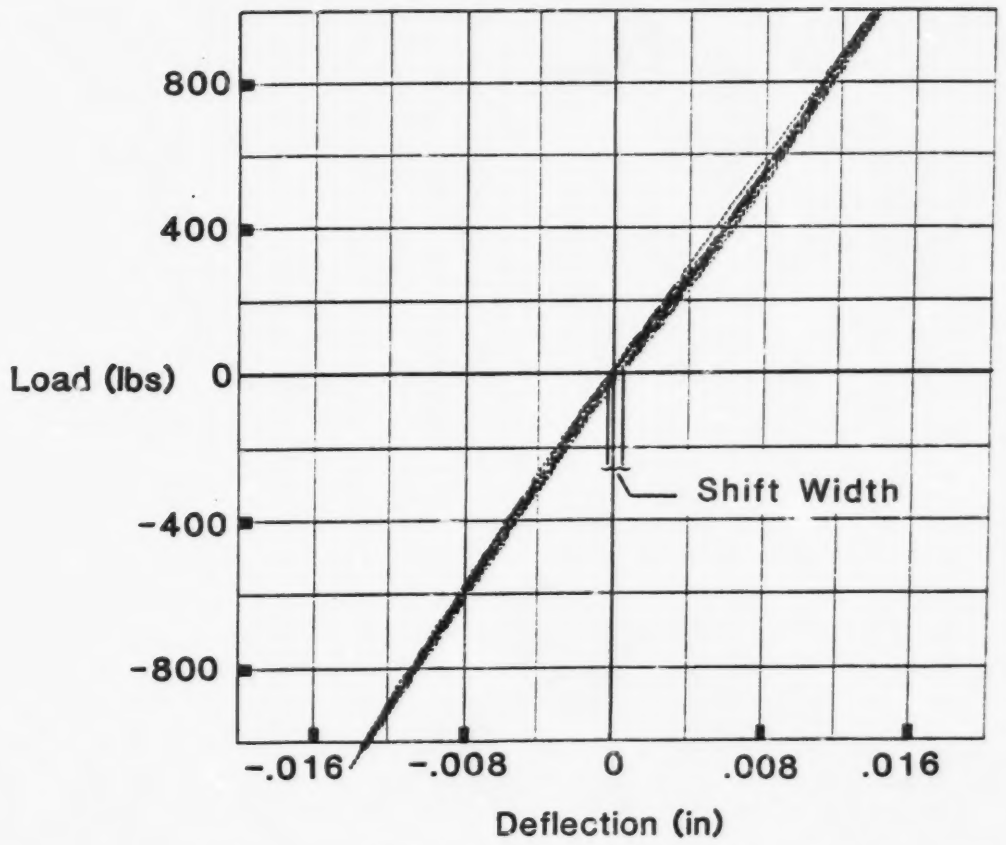

Figure 7.- Load-Deflection Curve for Specimen # 3
With Zero-Load Shift
(250 in-lbs Torque)

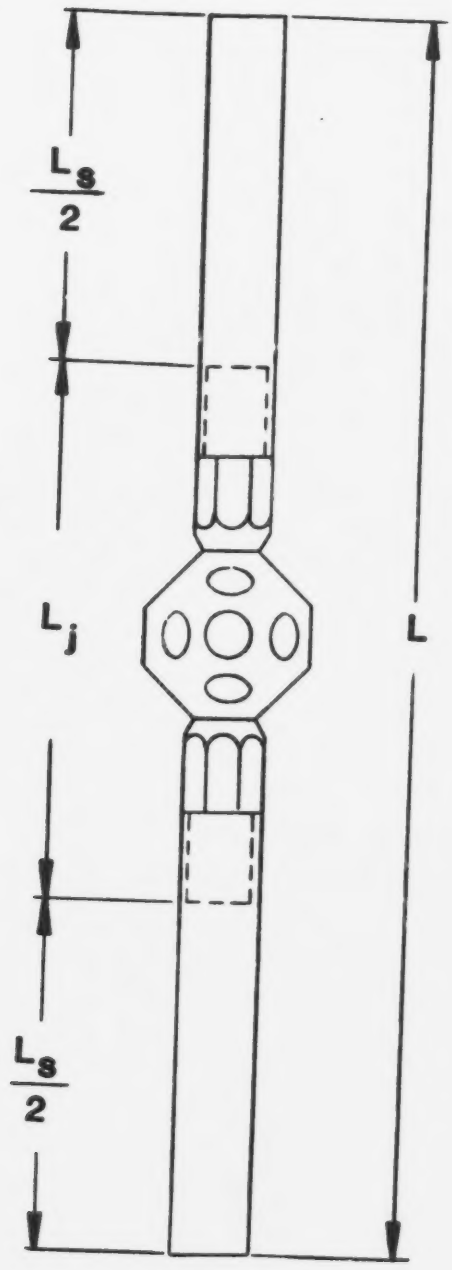

Figure 8. – Definition of Length Terms

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15. Supplementary Notes

16. Abstract

To aid in the prediction of the dynamic behavior of the Space Station, a one-tenth scale dynamic test model is to be constructed of commercially-available, small-scale truss hardware. Tests have been performed to determine the axial stiffness characteristics and failure loads of the truss joint. A parametric study has shown that the stiffness of the joint increases as the attachment bolt torque value is increased. Furthermore, at torque values equal to or higher than 250 in-lbs, hysteresis in the load-deflection curve is essentially eliminated. Also, the joint stiffness remained relatively constant between specimens. The effective stiffness of a joint subassembly tested is 76 percent that of the strut. Tensile and compressive failure occurred in the region of the bonded plug, with lower failure loads corresponding to compressive loadings.

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